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PROBE MEASUREMENTS OF THE BOUNDARY PLASMA PARAMETERS IN THE TM-1-MH TOKAMAK

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The paper is devoted to the measurements of plasma parameters in the scrape-off layer of tokamak TM-1-MH by means of a langmuir probe. On the basis of these measurements some qualitative estimations were drawn concerning the radial diffusion coefficient in the limiter region.

1. INTRODUCTION

Recently considerable attention has been given to the study of the plasma parameters in the scrape-off layer (limiter shadow) of tokamaks. The reason is that this boundary region surrounding a hot plasma core determines the power losses and thus also the energy and particle confinement time in tokamak systems. Moreover, the knowledge of the density profile in front of an antenna is necessary for a proper matching of the heating power going from an outer generator to the hot plasma core in the case of a supplementary hf plasma heating. This concerns especially the heating in the lower hybrid frequency region, which is the main physical problem to be investigated on the tokamak TM-1-MH.

Many of the present diagnostic methods used for tokamak plasma are not applicable to these purposes. For this reason several works dealing with the application of electrostatic langmuir probes in the periphery region have recently appeared [1–7]. This paper describes similar measurements of the boundary plasma in the tokamak TM-1-MH.

2. EXPERIMENTAL DESCRIPTION

Tokamak TM-1-MH is a small tokamak [8] with the following main parameters: major radius $R = 0{\cdot}4$ m, minor radius $r_0 = 0{\cdot}1$ m, radius of limiter $a = 0{\cdot}075$ m, toroidal magnetic field on the axis $B_0 = 1{\cdot}3$ T, and plasma current up to 30 kA.

The probe consists of a molybdenum wire (1 mm diameter by 5 mm long), the outer part of which is covered by corundum ceramics. This assembly is mounted on welded bellows which enable us to move the probe a total of 5 cm along the chord at a distance of 42 mm from the limiter diameter, in the cross section about 45° from the aperture type limiter with the radius $a = 75$ mm (for schematic arrangement see fig. 1). The wire probe is oriented in such a way that the current-collecting area is nearly perpendicular to the field lines. In the same cross section plane the pulse gas puffing is applied (piezoelectric valve, see [9]).

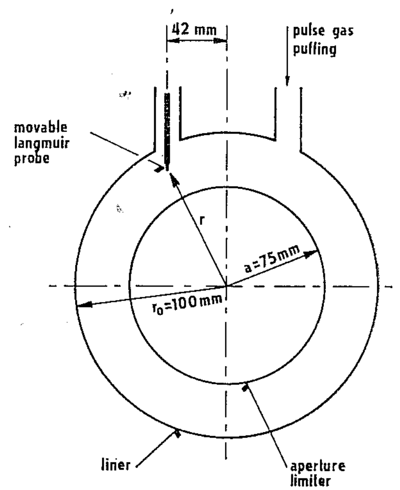

Fig. 1. The cross-sectional view showing the location of the limiter, the langmuir probe and the pulse gas puffing.

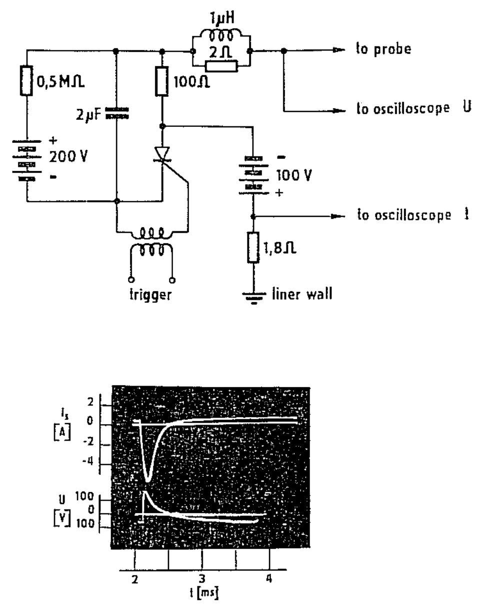

Fig. 2. a) The electronic circuit for the pulse measurement of the probe characteristics. b) The example of the probe characteristic.

The electronic circuit for the pulse measurements of the probe characteristics is shown in fig. 2a. In the stationary state the retarding voltage (usually −100 V) is applied between the probe and the liner wall. The course of the probe characteristics is obtained by discharging the capacity $C = 2$ μF through a tyristor in the required time. An example of such measurement in the quasistationary phase of tokamak discharge is given in fig. 2b. It is evident that the time-scale of the sweeping is less than one millisecond.

3. MEASUREMENTS OF THE BOUNDARY PLASMA PARAMETERS

Since the Debye length and the electron Larmor gyroradius are much smaller than the probe dimensions and the ion (hydrogen) Larmor gyroradius does not exceed these dimensions for energy smaller than about 20 eV, it is possible to use the approximation of a plane probe [10]. That means that the collecting surface A_p of the probe is the perpendicular cross section of the wire including the double sheath [11]

(but multiplied by two because the charged particles are collected along the magnetic lines of force on both sides, i.e. $A_p = 2 \times 5 \times 10^{-6}\,\mathrm{m}^2 = 10^{-5}\,\mathrm{m}^2$). As usual, the electron temperature can be determined from the slope of the characteristic on the logarithmic scale

$$T_e\,[\mathrm{eV}] = -\frac{dU}{d(\ln I_e)} \tag{1}$$

in the vicinity of the floating potential (I_e being the electron current) and the plasma density from the ion saturated current I_s^+:

$$n = 1{\cdot}13 \times 10^{20}\,\frac{I_s^+}{\sqrt{T_e}}\quad[\mathrm{m}^{-3}, \mathrm{A}, \mathrm{eV}]\,. \tag{2}$$

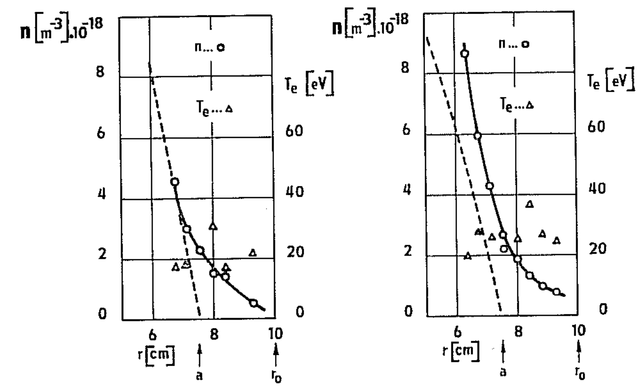

Fig. 3. The profile of the plasma density in the limiter region. a) without the pulse gas puffing, $n(0) = 2{\cdot}25 \times 10^{19}\,\mathrm{m}^{-3}$; b) with the pulse gas puffing, $n(0) = 1{\cdot}7 \times 10^{19}\,\mathrm{m}^{-3}$.

The results of the periphery plasma density and electron temperature probe measurements are given in fig. 3. Measurements were carried out in the time of 2 ms after the tokamak discharge beginning (in the quasistationary phase). Fig. 3a shows the case with the central density $n(0) = 2{\cdot}25 \times 10^{19}\,\mathrm{m}^{-3}$ (this value is obtained by a one-chord 4 mm interferometer; density distribution in the plasma core is assumed to be parabolic, with zero on the limiter) without the additional pulse gas puffing. Fig. 3b shows the case with a little lower central density ($n(0) = 1{\cdot}7 \times 10^{19}\,\mathrm{m}^{-3}$) but with an additional gas puffing. It may be seen that while in the first case the value of the density measured by the probe (full line) fits very well the assumed parabolic distribution (dashed line), in the second case, due to the additional flux of neutral gas, the periphery density is enhanced. Generally, it follows from these measurements that the density in the region of the limiter is not negligible and may exceed 20% of its central value. It decreases in the radial direction through the limiter shadow nearly exponentially with the diffusion length about 1 cm. The electron temperature is nearly constant in the limiter shadow and is about 20−25 eV.

4. ESTIMATION OF THE PARTICLE CONFINEMENT TIME AND THE BOUNDARY DIFFUSION COEFFICIENT

As was shown in the previous section, using the langmuir probe we are able to make a local measurement of the plasma density in the limiter shadow. As it is reasonable to assume that the plasma is not created here but is transported to the periphery from the hot dense plasma core by particle diffusion [7], then, comparing the time behaviour of the periphery and core plasma densities we can roughly estimate this particle transport time. Such estimation can be done e.g. on the basis of time shift

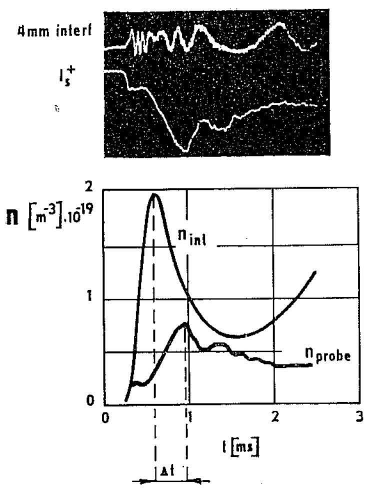

Fig. 4. The time dependence of the line averaged density measured by a 4 mm interferometer and of the local periphery density measured by the probe.

between the maxima of the ion saturated current and the line averaged density measured by the 4 mm interferometer, see fig. 4. Time shift Δt of about 400 μs observed in this measurement corresponds to the transport time of the ions from the core to the probe, i.e. it corresponds to the gross particle confinement time in this early stage of tokamak TM-1-MH discharge. It is worth mentioning that in the quasistationary state of the discharge the confinement time is about 2–3 times greater ($\tau_p \simeq 1$ ms as follows from the spectroscopic measurements).

Knowing the radial gradient of the density in the region of the limiter (see fig. 3) and the gross particle confinement time, one can estimate the radial diffusion coefficient $D_\perp$ using the general expression for the particle flux $\Gamma_\perp$:

$$\Gamma_\perp = D_\perp \nabla_\perp n \,. \tag{3}$$

Namely, the gross particle confinement time τ_p is determined by the following relation:

$$\tau_p \int_S \Gamma_\perp \, dS = \int_V n \, dV \,, \tag{4}$$

where S is the area of the flux surface given by the limiter (radius a) and V is the total

plasma volume. After the integration the latter relation can be written in the form

$$\tau_p \Gamma_\perp \, 2\pi a \, 2\pi R = \langle n \rangle \, \pi a^2 \, 2\pi R \,, \tag{5}$$

or finally

$$\Gamma_\perp = \frac{a\langle n \rangle}{2\tau_p} \,. \tag{6}$$

Here R is the major tokamak radius, $\langle n \rangle$ denotes the space averaged plasma density. Comparing eqs. (3) and (6) and substituting the typical values of a tokamak discharge we finally obtain the resulting expression for the perpendicular diffusion coefficient:

$$D_\perp = \frac{a\langle n \rangle}{2\tau_p \nabla_\perp n} = \frac{(7{\cdot}5 \times 10^{-2})(1 \times 10^{19})}{(2 \times 10^{-3})(5 \times 10^{20})} = 0{\cdot}75 \text{ m}^2 \text{ s}^{-1} \,. \tag{7}$$

Taking the parameters of TM-1-MH plasma at the edge of the limiter we obtain the following estimation:

$$D_{\perp \text{classical}} = \frac{\nu_e T}{m\omega_{ce}^2} = 1{\cdot}7 \times 10^{-4} \text{ m}^2 \text{ s}^{-1} \,,$$

$$D_{\perp \text{Bohm}} = \frac{T}{16 m\omega_{ce}} = 1{\cdot}2 \text{ m}^2 \text{ s}^{-1} \,.$$

Comparing these values with that of (7) it may be seen that the measured diffusion coefficient $D_\perp$ in the limiter region is of the order of $D_{\perp\text{Bohm}}$, i.e. perpendicular diffusion in this region has a turbulent character. It seems that this fact is a common feature of tokamak devices, as similar results were obtained in the papers [4, 5, 7] with only a little different geometry of the scrape-off layer. The reason is probably the fact that in the scrape-off layer of tokamaks the lines of force are short circuited by the limiter.

4. CONCLUSION

The paper describes an application of langmuir probe measurements of plasma parameters on the periphery of TM-1-MH tokamak. It was shown that while the density of plasma decreases approximately exponentially in the limiter shadow, the electron temperature is there nearly constant. Some interesting qualitative statements concerning the estimation of the gross confinement time in the initial phase of tokamak discharge were drawn on the basis of the comparison of the time behaviour of the periphery and line averaged plasma densities. For the quasistationary phase an attempt was made to estimate the radial diffusion coefficient using the measured radial density profile in the limiter region and the value of the gross particles lifetime from the spectroscopic measurements. It was shown that the diffusion at the plasma edge is of a turbulent type.

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